CropSyst VB – Simpotato, a crop simulation model for potato-based cropping systems: I. Model development

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Abstract

Crop simulation models, coupled with field data, can predict the fate and transport of N while providing basis for improved crop management practices. The potato crop simulation model Simpotato was integrated into the multi-year, multi-crop simulation model CropSystVB to improve overall model capabilities for the assessment of N dynamics in potato-based cropping systems. In the integrated model, CropSystVB simulates the soil-water-plant-atmosphere system for a crop rotation, as well as the water and nitrogen budgets. When the crop in the rotation is potato, Simpotato simulates potato growth and development and plant C and N balances. Descriptions of growth and phenology submodels of the Simpotato component are presented here since this model has not been well documented and was modified from its original version for this inclusion. In addition, a simulated scenario is included to illustrate model capacities for the prediction of the fate and transport of N under different N management and water levels for a typical crop rotation in the region.

Media summary

CropSystVB-Simpotato is the inclusion of the Simpotato model in the cropping systems model CropSystVB to predict fate and transport of N in potato-based cropping systems.

Key Words

Potato growth; Potato phenology; Nitrate leaching; Nitrogen Management; Irrigation management; US Pacific Northwest

Introduction

Nitrogen (N) leaching to groundwater tends to increase when water and N are applied in excess. Soils with low retention capacity for nutrients and water, and shallow-rooted crops increase the potential for N leaching. Potatoes are grown in the irrigated area of the US Pacific Northwest (PNW) as a major cash crop. This production occurs under irrigation systems, predominantly center pivots, and mostly on low organic matter sandy soils.

Improved N management practices combined with careful irrigation scheduling are necessary to increase crop nutrient uptake efficiency and minimize N losses to groundwater, but these effects are hard to quantify experimentally. Crop simulation models in conjunction with field data can be used to obtain more complete information about the fate of N under different scenarios of crop management (Peralta and Stockle, 2001).The overall objective of this study was to develop computer based tools that can be incorporated in a decision support system to optimize productivity of the potato-based agricultural systems of the US PNW while minimizing negative effects on the environment. The specific objective of this study was to describe the crop simulation model CropSyst-Simpotato and illustrate how it can be used to predict the fate and transport of N below the root zone of potato under different levels of N and water management practices.

Methods

The model

The model used in this study was the CropSystVB-Simpotato, a combination of the multi-year, multi-crop simulation model CropSystVB with the potato crop simulation model Simpotato (Hodges et al, 1992). CropSystVB is a Visual Basic new version of the CropSyst model (Stockle et al, 1994, Stockle et al., 2003) that is currently under development. CropSyst has been widely used to evaluate crop production and management strategies worldwide and specifically in the US PNW (Stockle et al., 2003). In the combineded model, CropSystVB provides the framework for weather, location, soil and crop inputs and for daily and annual soil and crop outputs. CropSystVB includes a mechanistic approach of the soil-water-plant-atmosphere system. It simulates crop growth and development and soil water and N balances for a crop rotation of several years. Simpotato is based on the CERES-maize type of model and simulates growth and development of potato. In CropsystVB-Simpotato, when the crop in the rotation is potato, the phenology and growth of potato, as well as the plant N and carbon (C) balances, are simulated by Simpotato.

Since Simpotato has not been well documented and was modified from its original version for this integration, a summarized description of growth and phenology submodels in the modified Simpotato version is presented here. Detailed description of CropSyst can be found elsewhere (Stockle et al., 1994; Stockle et al., 2003).

Simulation of development

In Simpotato, determination of pre-emergence stages, sprout germination and emergence, is based on management and soil thermal time. Germination of potato seeds occurs immediately after planting if seeds were planted with sprouts already present. Otherwise, germination and sprout growth depend on soil thermal time. Emergence occurs when the sprout length is greater than the planting depth. However, emergence date can also be treated as an input because of the variability and uncertainty of the effects of harvest and storage conditions on the rate of germination and sprouting. Seed reserves are used to support sprout and root growth during this stage.

Development during the post-emergence growing stages is simulated based on the induction that the plant receives from the environment to form tubers (tuber induction, *TIND*). Flowering is not simulated in Simpotato. Phenological post-emergence events are tuber initiation (*TI),* beginning of rapid tuber growth or bulking and maturity. Tuber induction is estimated using the approach in Substor potato crop model (Griffin et al., 1993). In the Substor model, *TIND* is a function of cultivar response to both temperature and photoperiod and both responses are modified by soil water and plant N status. The temperature and photoperiod effects on *TIND* are simulated by dimensionless cultivar-specific factors that range from 0 to 1. A daily tuber induction index is accumulated over the growing season and *TI* and the start of bulking occur when *TIND* reaches a predetermined threshold values.

From *TI* to the beginning of bulking, C partitioning occurs between tops, roots, and tubers. Bulking is the stage of dominant tuber growth. Tuber growth frequently ends (maturity) when all leaves senescence due to various stresses or as a result of defoliation in preparation for harvest.

Carbon assimilation, partitioning, and nitrogen balance

Growth (g carbohydrate plant^{-1}) in CropSystVB-Simpotato is the minimum of potential growth and available C. Potential growth is the sum of potential growth of leaves, stems, tubers and roots. Temperature is the main environmental factor that determines potential growth. Available C is the sum of potential C assimilation (*carbo*) and seed reserves. Potential C assimilation is computed as the minimum of light and water limited growth and is supplied by CropSyst.

From emergence to *TI*, only leaf, stem, and root growth occur. After *TI*, tuber growth is also calculated. By performing a C balance, potential growth is compared to available C. This balance attempts to match available C to potential growth. If available C is greater than potential growth, the excess C is discarded.

Otherwise, if available C is less than potential growth, growth is reduced. During tuber bearing stages and for determinant varieties, tuber growth is given first priority according to a crop parameter that sets the level of tuber priority for carbon allocation. The resulting growth is the amount of growth that will occur unless N is limiting.

Potential leaf growth is estimated from potential leaf area expansion using a cultivar-specific coefficient for specific leaf weight (g cm^{-2}). Potential leaf area expansion is obtained from daily thermal time, a cultivar-specific maximum leaf expansion rate (cm^2 $plant^{-1}$ day^{-1}) and water and N stresses. Potential stem growth is estimated initially to be 1/3 of that of potential leaf growth and then adjusted according to the C and N balances. Potential maximum tuber growth is calculated as the product of the cultivar-specific maximum for tuber growth rate (g dry weight $plant^{-1}$ day^{-1}) and the fraction of available C apportioned to tubers. This fraction depends on *TIND* and temperature. Nitrogen shortage reduces top growth and increases tuber growth. Available soil N is estimated by CropSyst and supplied to Simpotato. Leaf senescence due to normal aging is based on thermal time and existing leaf area. Senescence due to stress is estimated as the minimum of water, N, temperature and excessive leaf area stress factors.

Plant nitrogen demand *(Ndem)* is the N needed for optimum N concentration of existing biomass and new growth. If available N (*availN)* is greater than *Ndem*, leaf N concentration is set to the maximum allowable concentration. If *availN* is less than *Ndem*, leaf N surplus (if any) above a specified threshold is evaluated for redistribution. If N shortage persists, *Ndem* is based on new growth only. If *availN* is still not enough to match *Ndem*, growth is reduced until *availN* equals *Ndem*. During the tuber bearing stages, if demand and supply are not in balance, there is a shift of growth from leaves to stems and tubers according to the available N:C ratio.

A simulation example

An example is presented to illustrate model capabilities for the assessment of N dynamics in potato-based agricultural systems of the US PNW. Crop, soil, weather and management inputs are based on a potato N management experiment conducted by Alva (2003). A corn-potato-wheat rotation was simulated from 2001 to 2003 in a sandy soil in the Columbia basin, WA. Management of potato (Ranger Russet cultivar) included two pre-plant N application rates (0 and 112 kg/ha) and two levels of irrigation (100 and 130 % of potential crop evapotranspiration, ET). The total N applied for the entire potato growing season was 280 kg/ha for all treatments. The in-season N was split in five applications. Total N applied to corn and wheat were 250 and 130 kg/ha, respectively, and the irrigation for these two crops was that to replenish potential crop ET.

Results

Simulated N transport below 2 m depth soil during the growing seasons of potato and wheat and during the winter period following potato are shown in Table 1. Results show that irrigation level is the most important factor contributing to fate of N. Transport of N below 2 m was almost negligible when the applied water was just enough to fulfill crop potential ET. Comparing N pre-plant N rates with irrigation at 130% of potential crop ET, N transport below 2 m during the potato growing season and during the winter period following potato was greater for the pre-plant N rate of 112 kg/ha than for the 0 rate. High soil N at the beginning of the growing season in the 112 pre-plant rate and excess irrigation water increased the amount of N transport below 2 m during and after the growing season of potato.

Table 2 shows potato and wheat N uptake and fresh tuber yields. Simulated tuber yield decreased with increased irrigation levels, at both pre-plant N rates. Increased N transport below the root zone affected the available N for crop uptake, particularly during the first part of the growing season. Low potato yields correspond to low N uptake. Nitrogen in the soil profile (2 m depth) at harvest of potato for the 130% ET treatments was distinctly higher than for the 100%ET (Fig.1). A large portion of this soil N was, however, below the root zone of potato (0.6 m), thus was not available for uptake by potato crop (Table 2). Nitrogen uptake by wheat was not significantly different among treatments despite the different amount of N in the profile at the beginning of the growing season. Much of the N left by potato in the soil profile was located in the deep layers, and therefore largely unavailable to wheat, at least at the beginning of its growing season.

Table 1. Simulated N leaching (kg/ha) below the 2 m depth for the combined treatments of 0 (PP0) and 112 (PP112) kg/ha of N at pre-planting and irrigation levels to supply 100% (100%ET) and 130% (130%ET) of potential crop ET.

N Leaching (kg/ha)	PP0-100%ET	PP0-130%ET	PP112-100%ET	PP112-130%ET
Potato growing season	0	19.5	0	30.1
Winter after potato	0.1	26.1	0.1	30.7
Wheat growing season	1	13.8	1	10.8

Table 2. Simulated N uptake (kg/ha) by potato and wheat and tuber fresh yield.

	PP0-100%ET	PP0-130%ET	PP112-100%ET	PP112-130%ET
N potato uptake (kg/ha)	248	165	241	186
N wheat uptake (kg/ha)	159	162	149	147
Tuber fresh yield (Ton/ha)	89	66	83	73

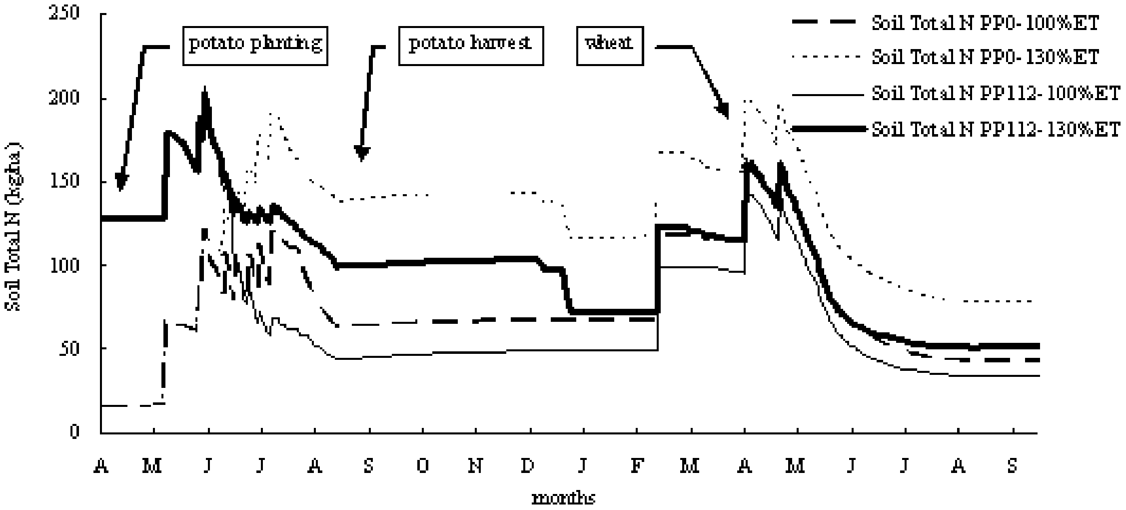

Figure 1. Simulated total soil N (kg/ha) during the growing seasons of potato and wheat.

Final remarks

Results illustrated how the CropSystVB-Simpotato model can be used to assess N transport and losses under different water and N management practices. The Simpotato component is based on the balance of plant available C and N. The inclusion of Simpotato into CropSyst gave the combined model improved capabilities to estimate soil and plant N dynamics and production of potato-based cropping systems.

Example simulations showed that irrigation level above potential crop evapotranspiration in potato appears as a main factor influencing N transport in predominantly irrigated Pacific Northwest production region in the US. Timing of fertilization influenced the N transport in the soil profile. High rate of pre-plant N application increased the transport of N deeper in the soil, thus, unavailable to crop uptake.

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